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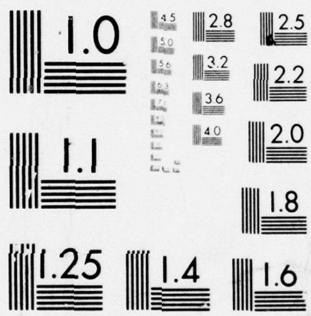

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ARCTIC RADIATION FLUXES--THE LONG WAVE RADIATION TRANSFER IN ARCTIC STRATUS CLOUDS

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April 1977

FINAL REPORT

Contract N00014-75-C-0433

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This research was sponsored by:

Office of Naval Research
Arctic Program
Earth Sciences Division
Arlington, Virginia 22217

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(9) Final rept. 1 Jan 76-30 Sep 77

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) ARCTIC RADIATION FLUXES--THE LONG WAVE RADIATION TRANSFER IN ARCTIC STRATUS CLOUDS.		5. TYPE OF REPORT & PERIOD COVERED Final Report Jan. 1, 1976-Sept. 30, 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) K.O.L.F. Jayaweera		8. CONTRACT OR GRANT NUMBER(s) (15) N00014-75-C-0433
9. PERFORMING ORGANIZATION NAME AND ADDRESS Geophysical Institute University of Alaska Fairbanks, Alaska 99701		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Arctic Program, Earth Sciences Division Office of Naval Research 8000 N. Quincy Street, Arlington, Va. 22217		12. REPORT DATE (11) Apr [redacted] 77
		13. NUMBER OF PAGES 25 (12) 26p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Stratus clouds, temperature and emissivity profiles, ice crystals

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Stratus cloud cover over Barrow, AIDJEX camp 'Big Bear' and over the Beaufort Sea was derived for 1975 using surface and satellite observations. Contrary to the reported value of the consistently high long term summer mean cloudiness, the values for 1975 showed a period of complete lack of cloudiness. Comparison with the wind field suggests that a southerly component in the 700 mb winds corresponds to an increase → next page

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in cloudiness and a northerly component corresponds to a decrease. The unusual northerly 700 mb flow during this year may explain both the low summer cloudiness and the severe ice conditions in the Beaufort Sea. The temperature and emissivity profiles measured using unstrumented aircrafts indicated that within a few days of formation of stratus cloud overcast the emissivity at the top part of cloud becomes low and the temperature inversion drops down to the middle part of the cloud. Continuous solar heating and the effect of scattering in the long wave may be responsible for these changes.

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ABSTRACT

Stratus cloud cover over Barrow, AIDJEX camp 'Big Bear' and over the Beaufort Sea was derived for 1975 using surface and satellite observations. Contrary to the reported value of the consistently high long term summer mean cloudiness, the values for 1975 showed a period of complete lack of cloudiness. Comparison with the wind field suggests that a southerly component in the 700 mb winds corresponds to an increase in cloudiness and a northerly component corresponds to a decrease. The unusual northerly 700 mb flow during this year may explain both the low summer cloudiness and the severe ice conditions in the Beaufort Sea. The temperature and emissivity profiles measured using unstrumented aircrafts indicated that within a few days of formation of stratus cloud overcast the emissivity at the top part of cloud becomes low and the temperature inversion drops down to the middle part of the cloud. Continuous solar heating and the effect of scattering in the long wave may be responsible for these changes.

INTRODUCTION

During the summer months low stratus clouds cover the Arctic basin almost continuously. This persistent cloudiness appears to be a permanent climatalogical feature and hence has important implications for the radiation budget of the Arctic. Early investigations of cloud cover amounts by Huschke (1969), Vowinckel and Orvig (1970) and Henderson (1967) showed that the amount of cloudiness and the frequency of occurrence are essentially a step function of time and that the increase of cloudiness during the summer is due to the presence of low level stratus. The layering feature of these clouds was reported by Jayaweera and Ohtake (1970) who also indicated that these clouds are essentially supercooled with few ice crystals.

A mechanism for the formation and layering of arctic stratus was given by Herman and Goody (1976). They suggested that condensation is induced in initially unsaturated continental polar air as it flows over the pack ice, the condensation is induced by diffusive cooling to the colder ice surface and long wave emission to space. Intense mixing within the cloud is generated by a strong cooling due to radiative emission at the cloud top. The layered structure is attributed to a greenhouse mechanism whereby solar radiation penetrates to the interior of the cloud and causes evaporation there. At the same time the top remains cold due to long wave emission to space and the base remains cold since the surface temperature is fixed near $0^{o}C$. Herman and Goody's model predicts that condensation will occur within a day and the clouds will persist over several days due to the absence of effective dissipative mechanisms.

In this report we re-examine the cloud cover amounts over the Beaufort Sea using surface observations and satellite imagery. The cloud cover amounts are then compared with the wind field to infer the large scale air flow during the cloud cover conditions. The stratus clouds have low liquid water content, hence their emissivities are considered to be less than 1 thereby making it difficult to estimate long wave radiative fluxes from observations of the cloud top temperature. In addition to cloud cover amounts, this paper also reports measurements of vertical profiles of emissivity and air temperature of stratus clouds during a cloud episode over the Beaufort Sea near Barrow.

CLOUD COVER AMOUNTS

(a) Mapping

This study was limited to the region shown in Fig. 1. This area covers the Beaufort Sea, Alaskan coast and the AIDJEX area. The cloud cover amount for this area was obtained from the imagery of the NOAA 3 and 4 satellites. The satellite imagery for the (Very High Resolution Radiometer) (VHRR) are available in the visible band (0.6 to 0.7 μm) and the thermal infra-red band (10.512.5 μm) with a resolution of 1 km. Many techniques are available for mapping clouds from satellite imagery for lower latitudes. But in the Arctic, the underlying snow or ice cover and the existence of temperature inversions at the lowest layers in the clouds make these techniques inapplicable. Furthermore it is not possible to develop a standard identification strategy applicable in all cases for the mapping of arctic stratus clouds.

The method adopted to map arctic stratus clouds is to utilize both the visible and infra-red imagery and use the features such as shadows

and highlights in the visible and abrupt temperature changes in the infra-red. The solar elevation in the arctic is low and in summer sunlight is available most of the time. The stratus clouds in the visible show highlights on the side facing the sun and dark shadows on the other side. Thus clouds often appear as an indentation in the imagery (see Fig. 2a), although the contrast in the albedo is small. From the position of the sun it is possible to distinguish the clouds from the surface. This method is satisfactory unless the entire area of Arctic ocean in the satellite image is cloud covered so that the cloud layer can be mistaken for the ice surface. Under these circumstances the exact location of the coastline can be used to help in the differentiation of cloud from the ice surface. The infrared imagery often shows sharp contrasts in temperature between cloud tops and ice surface. These differences may be especially enhanced as shown in Fig. 2b so that isotherms can be drawn. Sharp changes in temperature are assumed to be a boundary between two cloud layers or between a cloud layer and the ice surface. Using these characteristics we were able to map the cloud cover of arctic stratus for all the satellite imagery available during the year of 1975 for the area shown in Fig. 1. The cloud amount is defined as the fraction of the area covered by clouds other than high cirrus.

In addition, surface observations of cloud cover are available from the weather service office at Barrow and from meteorological observation at Big Bear camp of AIDJEX. The latter are available from April until August.

(b) Results

The weekly mean cloud cover amount from May until September 1975 is shown in Fig. 3. Although the mean cloud cover is still rather high (~6/10) and is not much different from the previous estimates of Huschke (1969), Vowinckel and Orvig (1970), the present results show considerable fluctuations in the weekly cloud amount for the year 1975, especially over the Beaufort Sea and 'Big Bear' Camp. Because our results were confined to one year, this particular year may have had anomalous cloud cover conditions. Indeed, the weather conditions departed considerably from the mean conditions for 1975, giving rise to anomalous ice conditions (Wendler and Jayaweera 1976).

Another inference from Figure 3 is that the cloud conditions at Barrow are considerably different from those over the AIDJEX camp. These results show that cloud condition could vary considerably from place to place especially for stations near the coast where the presence of land may have local effects. Therefore, inferences on the cloud cover situations over the Arctic Ocean from near-coast and land based stations must be made with care.

Herman and Goody (1976) suggested that stratus clouds are initiated by condensation on continental polar air as it moves over the cold ice pack. In order to test this suggestion we compared the daily surface, 850 mb and 700 mb North-South wind component at Barrow with the cloud cover amount. The comparison shows that a good relation is found between the cloudiness and the southerly wind component at 700 mb level (See Fig. 4). The surface winds showed no correlation at all, while a correlation with winds at 850 mb was inconclusive. This comparison

supports Herman and Goody's contention to the extent that cold arctic ice causes stratus clouds through modification of synoptic scale continental air above the boundary layer. Low-level flow may give rise to arctic fog, but stratus clouds are not necessarily formed by the lifting of these fogs.

Lack of 700 mb winds at the AIDJEX camp made it impossible to compare the wind directions and cloud cover over the camp. However the National Weather Service synoptic maps at 700 mb may be utilized for comparison with the cloud cover over Beaufort Sea. The mean 700 mb flow was computed for two weekly periods from April until August of 1975 for this region. For all the periods except from mid-June to mid-July the mean flow showed a northerly component. For this period the winds were northeasterly over the Beaufort Sea. This rather qualitative analysis tends to confirm that the lack of cloudiness during this period coincides with the change in wind direction from southerly to northerly. In order to confirm if a close correlation exists between the wind and cloud cover a detailed analysis of the 700 mb wind field is necessary.

COMPARISON BETWEEN ICE AND CLOUD COVER

The summer of 1975 was noted for its unusual ice conditions in the Beaufort Sea. The ice movement was late and was incomplete. Analyzing the meteorological situation pertaining to the movement of ice, Wendler and Jayaweera (1975) found that a persistent low pressure system over the high Canadian Arctic added a northwesterly wind component to the average wind; the resulting wind kept the ice near to shore. Using the deviations of the height of the 700 mb level for summer 1975 from the long term mean, they showed that the wind vector showed a southerly

component only in June. For the remainder of the summer there was a persistent northerly component. Except in early June, the cloud cover this year is consistently less than those inferred from past climatological data. Therefore less than usual offshore ice movement seems to be related to the less than usual cloud cover over the Beaufort Sea. Both these factors show their strong dependence on the 700 mb synoptic-scale wind field over the area.

VERTICAL TEMPERATURE AND CLOUD EMISSIVITIES

The meteorological properties of the stratus clouds and the environment, such as humidity, air temperature and the upward spectral thermal radiation temperature in the atmospheric window region, were measured during two periods. The first, in July 1975 utilized the NCAR electra aircraft; the second, in May 1976, utilized a Cessna 180. The former was in conjunction with the AIDJEX radiation program. The cloud properties were obtained during two days, July 19th and 23rd. The observations of May 1976 were designed to study the variations of cloud properties during a single stratus cloud episode. A stratus cloud episode is defined as a period through which the sky over Barrow is overcast without a break. Twice daily measurements of temperature, relative humidity and the spectral radiative temperature were obtained during a cloud episode which started on May 20th and lasted until May 26th. The spectral radiometer used during these experiments was a Barnes PRT-5 radiometer. A thermistor was used for air temperature measurements, and the humidity was measured using a Vaiisala-hygrometer.

The Barnes PRT-5 radiometer was mounted looking down so that it was measuring the upward spectral radiance. If R, is the upward long wave flux at the bottom of the cloud layer, R_2 the upward long wave flux at the top of the layer and σT^4 is the black body radiation at the average temperature of the cloud layer, then the emissivity is

$$E = \frac{R_1 - R_2}{R_1 - \sigma T^4}$$

This expression can be used to calculate the effective flux emissivity of any stratus cloud or a layer thereof.

A disadvantage of using upward radiance to determine emissivity is the influence of the underlying surface. As pointed out by Griggs (1968), the radiance coming out at the top of the layer becomes insensitive to emissivity when the cloud temperature is close to that of the ice surface below. Therefore for very low thin clouds, such as fogs, the value for emissivity obtained by this method may be in error.

The vertical temperature and radiance flux measurements using the Cessna 180 were made in the vicinity of Barrow. The first flight was made on the first overcast day after a period of partial cloudiness. The measurements of air or cloud temperature, spectral radiative temperature from PRT-5 radiometer and the humidity of air were made at various altitudes below, within and above the clouds. These measurements were made by flying for about 3 minutes in horizontal legs. The experimental legs were vertically above each other and separated by about 100 m. During the six day cloud episode, measurements were made in the morning and afternoon of every day.

The thermistor sensor, which measured the outside temperature, was mounted at the underside of the right wing of the aircraft and was shielded with reflective material to avoid icing and solar heating. The sensor was calibrated before and after every experiment run, using an ice bath. The output was recorded on a multivolt-meter single pen recorder.

The Barnes PRT-5 radiometer was mounted inside the cabin over a porthole so that it is looking directly downwards. The performance and accuracy of the instrument were checked by flying about 100 feet above a lead. During the entire duration of the experiment, the indicated radiative temperature of the PRT-5 over a lead was -1.8^{0}C. Very little or no turbulence occurred during any of the runs, hence the effect of slight pitching and rolling of the aircraft on the look-direction of the PRT-5 were considered to be negligible.

The profiles of outside temperature (air temperature) and the PRT-5 spectral radiative temperature (IR temperature) for 3 experimental runs are shown in Figs. 2 a, b and c. The cloud conditions during the three days described below correspond to three distinct situations of the stratus cloud during this particular episode.

(1) May 21, 1976: 1402 - 1439 Local Time.

May 21 was the second day of the stratus cloud episode. The profiles for this day, shown in Fig. 5a, and that of the previous day were similar. They are representative of stratus cloud conditions found elsewhere. The cloud was thick enough to be black, and the radiative temperature at cloud top was nearby equal to that of its cloud top temperature. Furthermore, radiative cooling at the top gave rise to a sharp temperature inversion at the top of the cloud. The cloud top was well defined.

(2) May 22, 1976: 9:20 - 10:09 Local Time

The profiles within the cloud showed marked changes on this day. The cloud top was tenuous so that it was difficult to measure its exact altitude. In Figure 2b the maximum observed height is indicated. Variation by as much as 500m was observed during five up and down passes through the cloud top performed intentionally to determine its height. The temperature structure was unlike that of the previous day with the inversion occurring less than half-way from the cloud base. Even for the rest of the lower section, the temperature was very peculiar with the top three quarters having no effect on the radiance flux emitted by the cloud. This peculiar profile is quite contrary to accepted profiles of stratus clouds. The temperature inversion near the middle of the cloud and a steady temperature increase all the way to the top may indicate the effect of solar heating. But the steady IR temperature is most peculiar and may indicate the importance of scattering (see for example Platt 1972). Further measurement may be required to confirm this effect prior to calculating the transmission coefficient of scattering.

(3) May 24, 1974: 10:30 - 11:10 Local Time

This is the first instance where the situation described above changed into a different type wherein the cloud developed an interstice giving rise to two layers. It is interesting that the interstice occurred about the same height where the temperature inversion occurred on May 22 (Fig. 5b). The lower cloud has its base lowered but inversion conditions and radiance effects are very similar to that shown in Fig. 5b. The top layer has become thicker and the increase in cloud temperature

is reflected in the flux radiance. Here again the sharp temperature increase at the cloud top is not observed. In the two cloud layers, the thickest part of the cloud is in the lowest section of the bottom layer. The high emissivity values indicate a high liquid water content for the lower parts of the cloud (Paltridge 1974).

Later on in the afternoon of this day, an altrostratus layer at a much higher altitude was observed in the north. Passes under this cloud showed that it had a considerable effect on the profiles of air and IR temperature of the upper layer but no effect on the lower layer. The effect of this higher cloud was to increase temperatures and radiance of the top layer.

Prior to the end of the cloud episode on May 26, a flight through the cloud showed that the clear interstice had disappeared, giving the impression of one solid layer of near 1600 m thick. However the cloud was very tenuousin the top one half with clear regions at irregular intervals. The temperature profile showed an initial small decrease in the temperature in the lower half of the cloud and an inversion with a slight increase in temperature in the region where the cloud was tenuous.

DISCUSSION

Except for one case of a stratocumulus reported by Platt (1972) the temperature and spectral radiance profiles described in this report are unique in character. The development of arctic stratus clouds is not by radiative cooling at the top, but rather at the bottom. The continuous sunlight during the summer shows its effect by warming the top part of the cloud so that considerable increase in temperature occurs with the inversion near the middle part of the cloud. The development of

interstices is where the solar radiation effects supercede longwave cooling, or near the inversions. As suggested by Herman & Goody (1976), solar radiation can penetrate further into the cloud while longwave cooling effects are confined to the top and bottom. Therefore we may expect to find disappearance of the cloud in the middle two layers. The result of continuous solar heating is to make the top layers of the cloud very tenuous, hence they have negligible effect on the longwave radiance flux. The small amount of radiation emitted by the cloud particles may be scattered away so that, even with a considerable increase in the cloud temperature, the longwave flux remains essentially a constant through the top part of the cloud.

The results described here are preliminary and need verification. The profiles described show the considerable effect the stratus clouds have on the radiation field and hence on the heat budget of the Arctic. The appearances and disappearances of the cloudiness seem to be related strongly to the wind field. This observation is consistent with that of Reed and Kunkel (1960). Southerly flow advecting warm air shows a high correlation with the formation of cloudiness. The primary source for dissipation of these summer stratus clouds is the advection of cold dry air from the north.

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Characteristics of Arctic Stratus Clouds over Beaufort Sea during AIDJEX, submitted to AIDJEX Bulletin.

Papers submitted at meetings:

Physical and Radiative Properties of Summer Clouds in Alaska from Satellite Imagery, International Cloud Physics Conference, Boulder, Colorado, July 26-30, 1976.

Distribution and Radiative Temperatures of Arctic Stratus Clouds using NOAA-4 Satellite Imagery, Symposium on Radiation in the Atmopshere, Garmich-Partenkirchen, W. Germany, August 19-28, 1976.

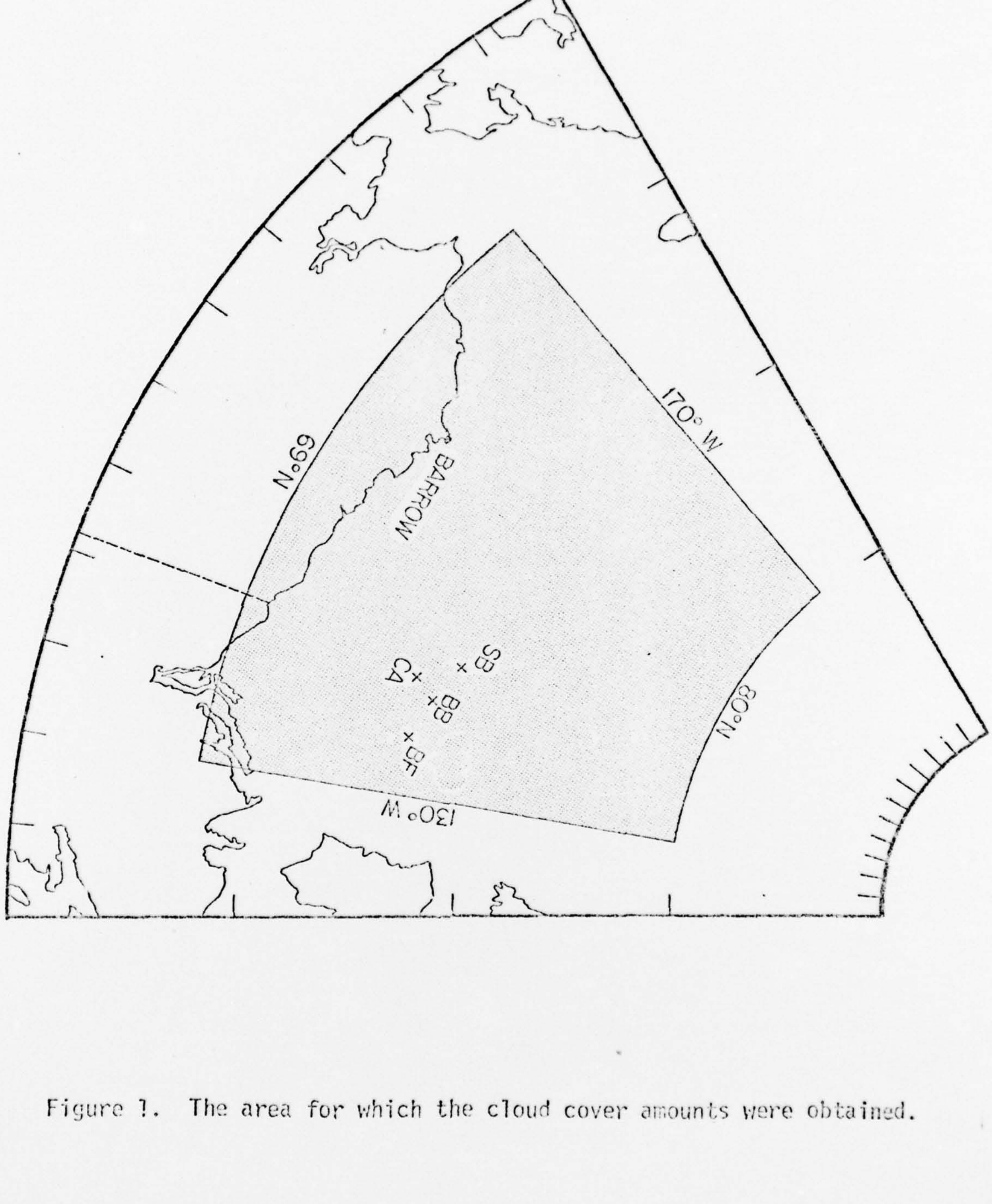

Figure 1. The area for which the cloud cover amounts were obtained.

Figure 2a. A NOAA-4 satellite image in the visible band showing arctic stratus clouds as indentation.

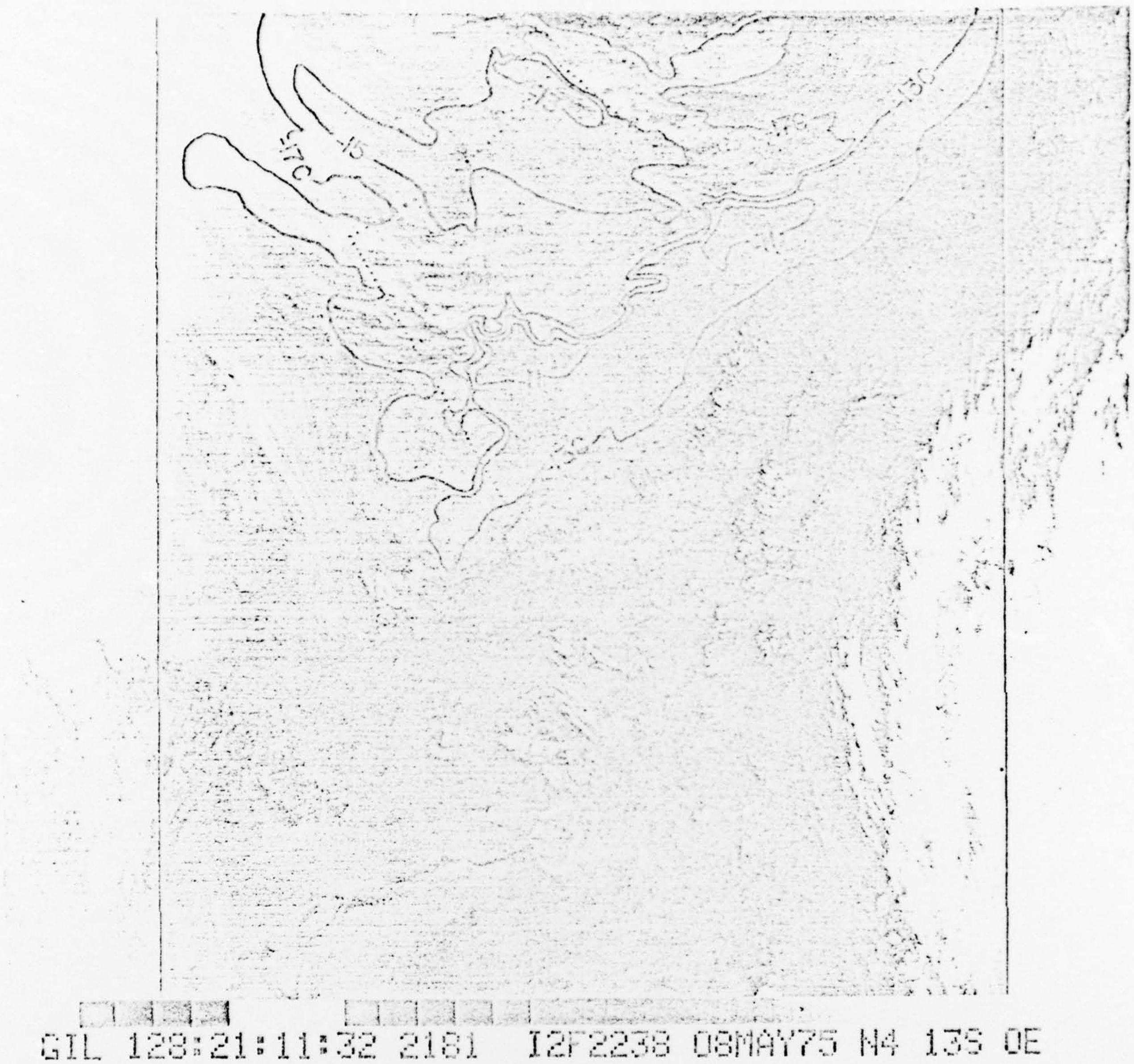

Figure 2b. An enchanced infra red image for the same as (a) showing radiative temperature isotherms. (The distance between the two vertical lines is 2000 km).

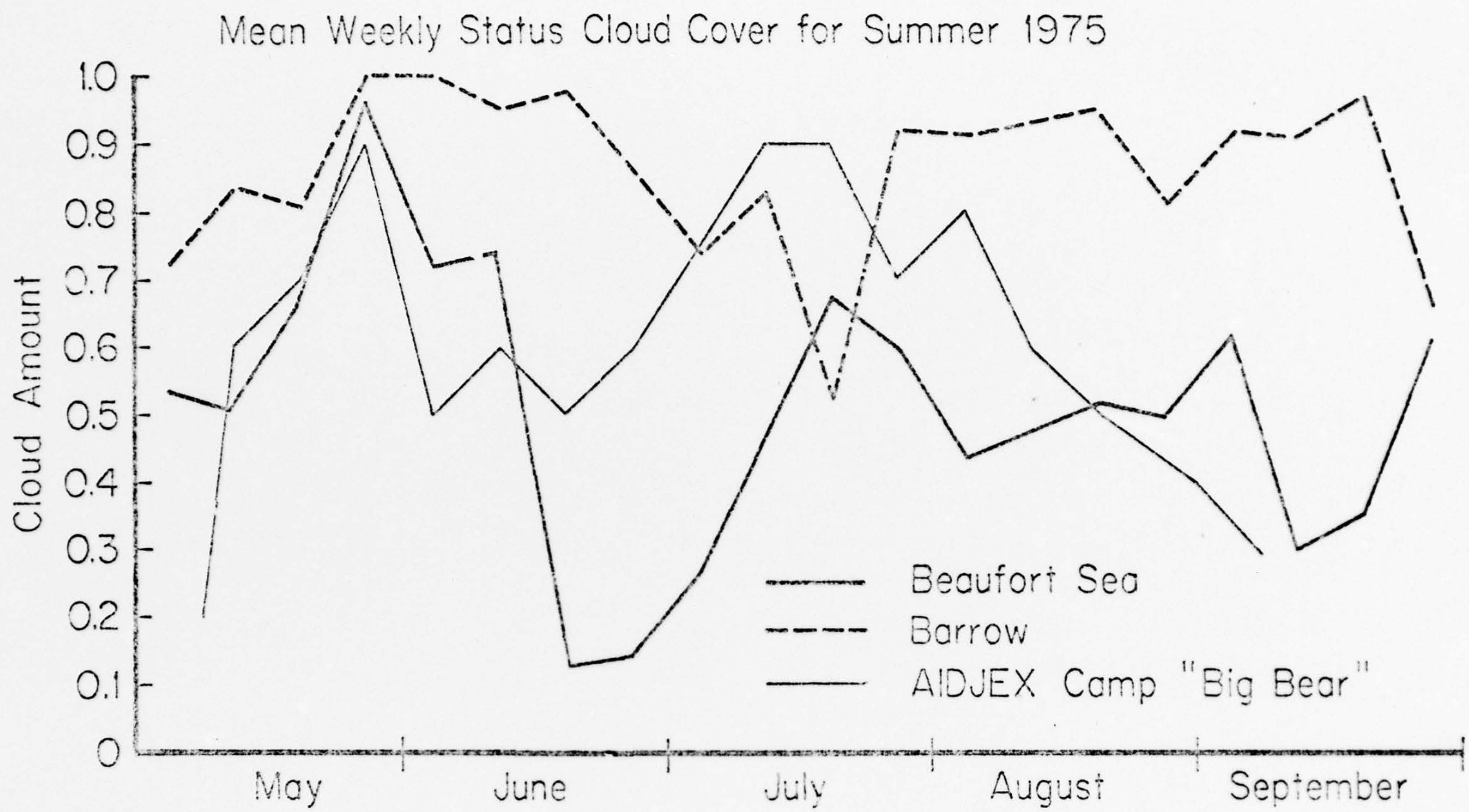

Figure 3. Weekly mean cloud cover amounts over the Beaufort Sea, AIDJEX camp 'Big Bear' and Barrow for 1975.

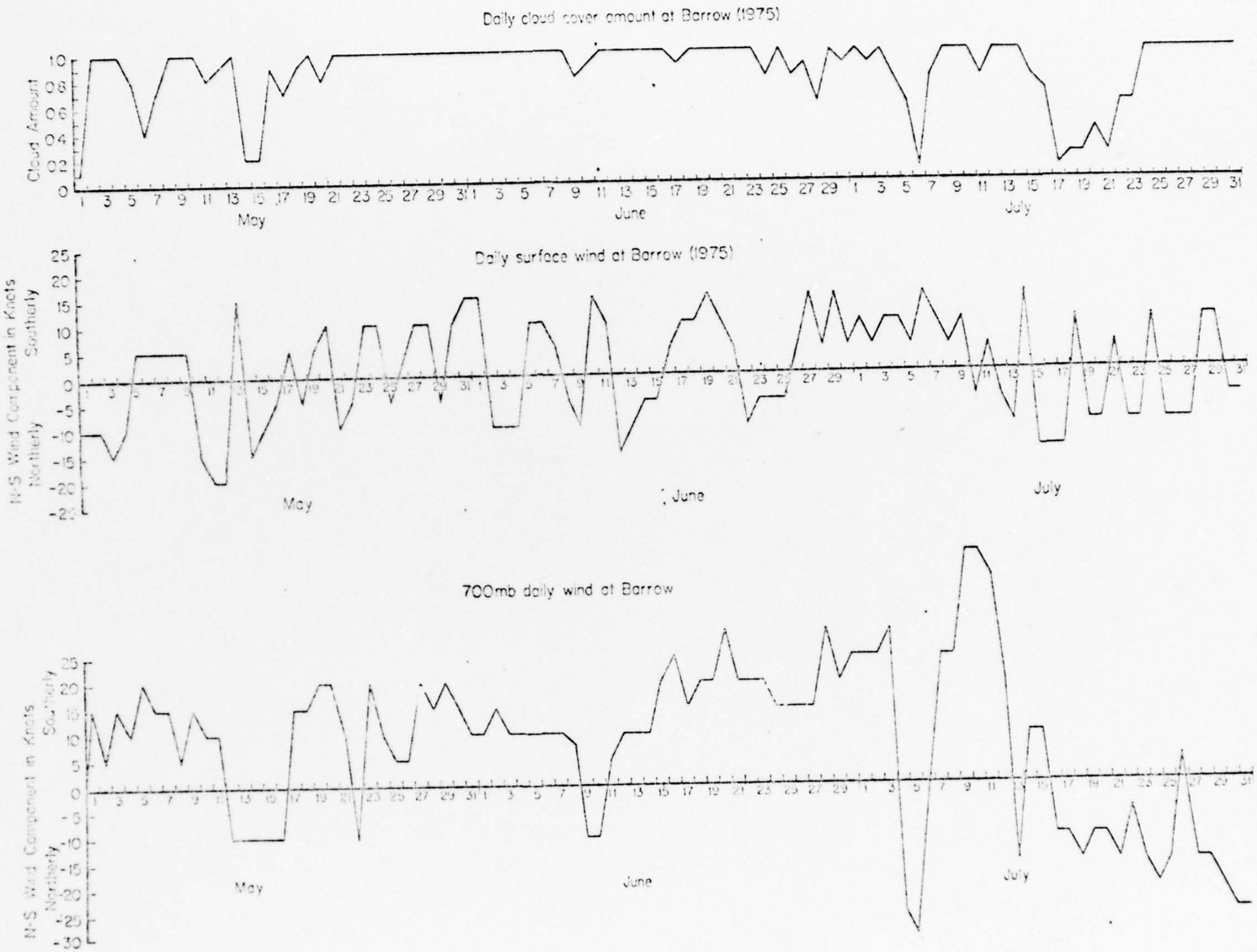

Figure 4. A comparison between cloud cover amount of Barrow with the north-south wind component at surface and 700 mb level.

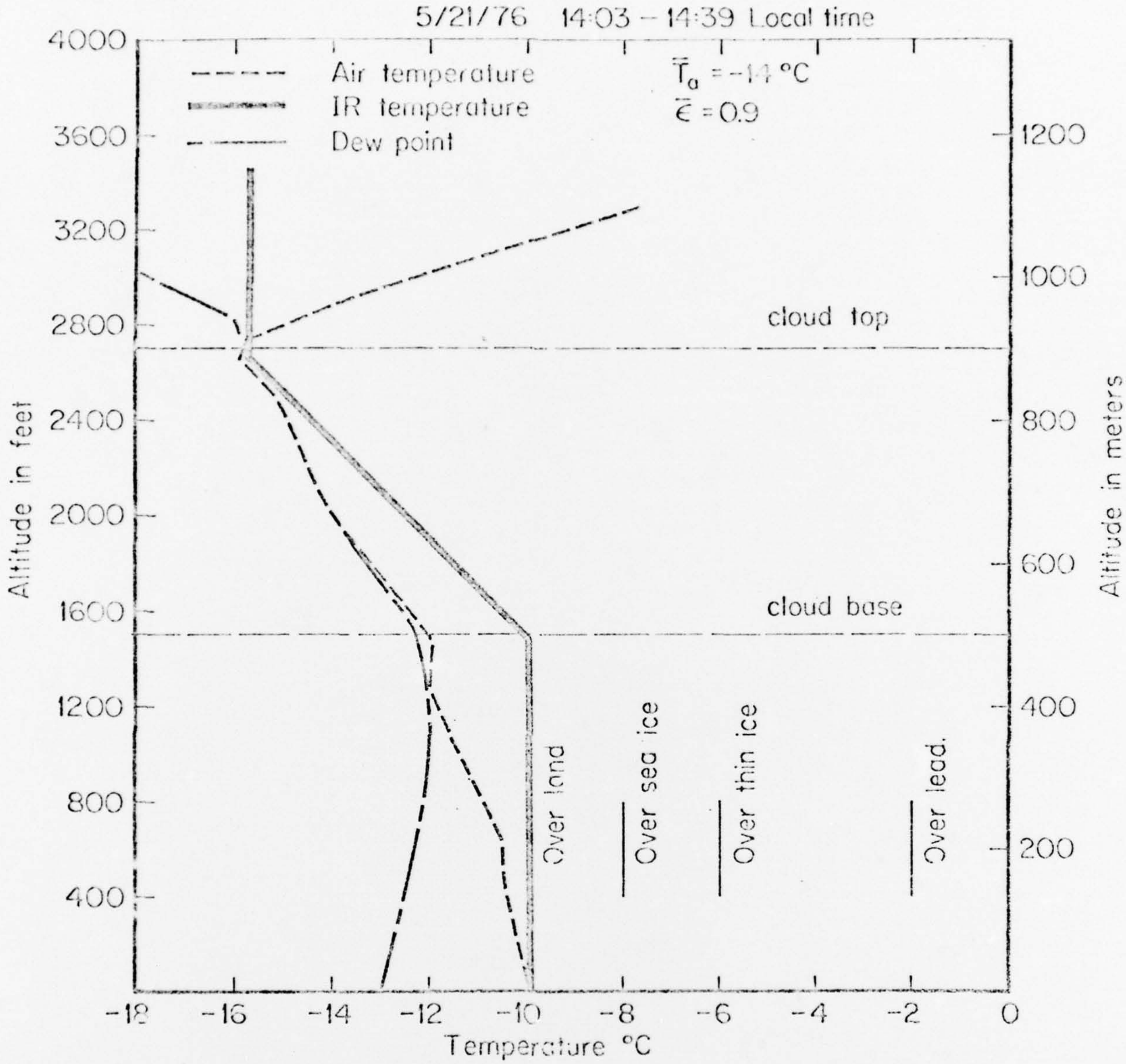

Figure 5a. Air, IR and dew point temperature profiles below, within and above the stratus clouds.
May 21, 1976 14:02 - 14:39 Local Time
The emissivity (E) values for various cloud layers are indicated.

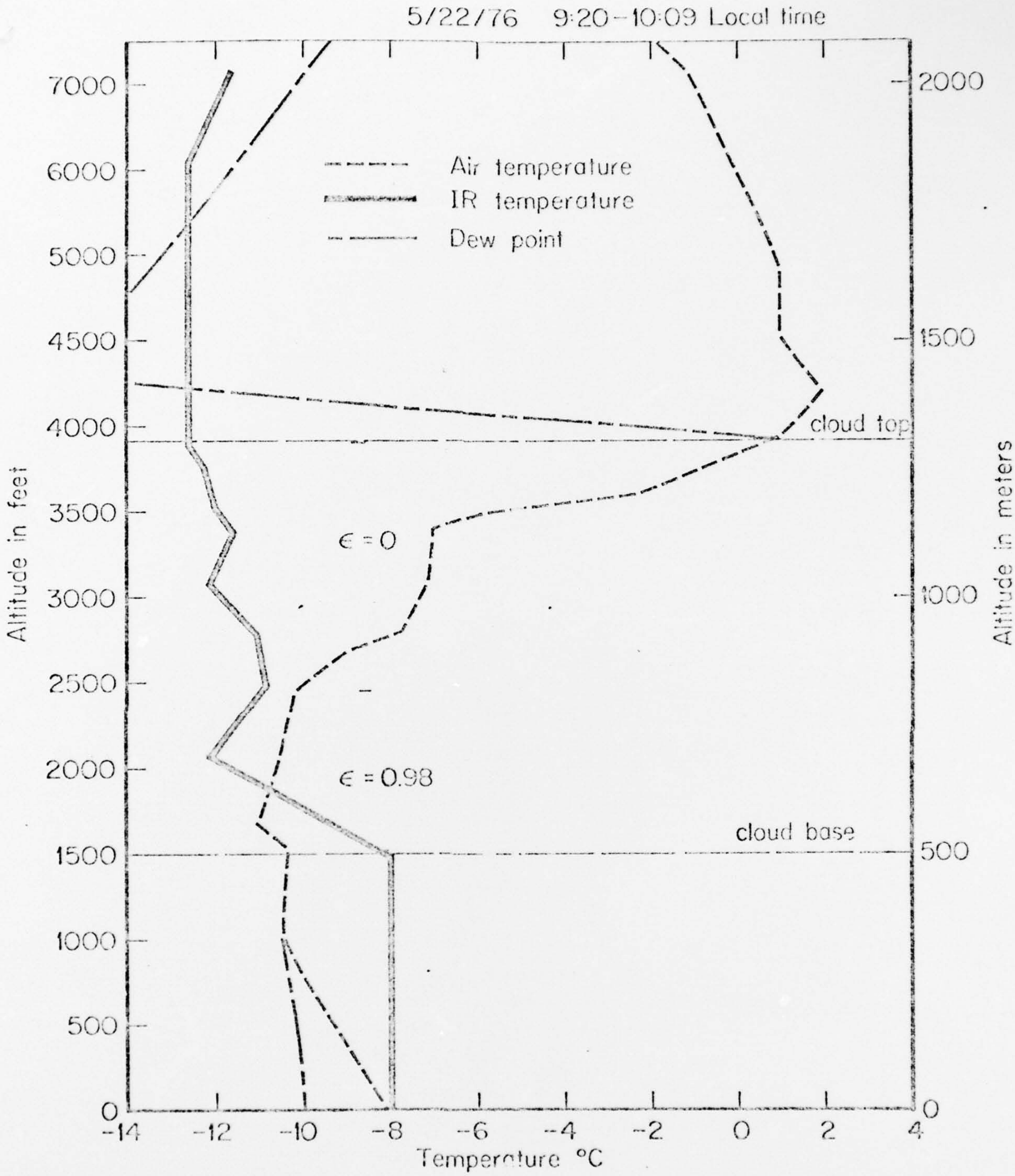

Figure 5b. Air, IR and dew point temperature profiles below, within and above the stratus clouds
May 22, 1976 09:20 - 10:09 Local Time
The emissivity (E) values for various cloud layers are indicated.

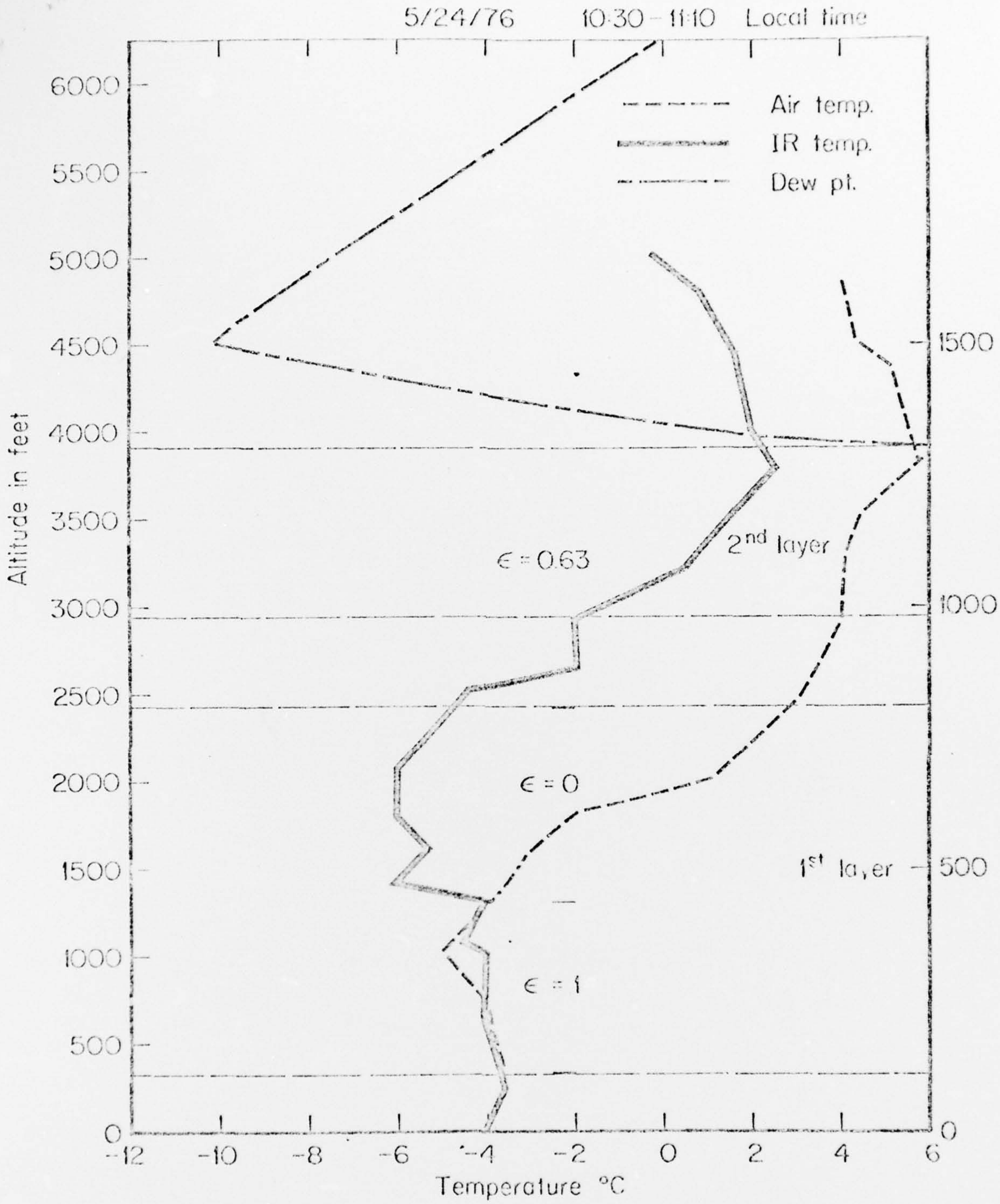

Figure 5c. Air, IR and dew point temperature profiles below, within and above the stratus clouds.
May 24, 1974 10:30 - 11:10 Local Time
The emissivity (E) values for various cloud layers are indicated.